TOWARDS ENHANCING GAIT SYMMETRY AND METABOLIC COSTS FOR AMPUTEE GAITS WITH A POWERED TRNASFEMORAL PROSTHESES

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INTRODUCTION

The Amputee Coalition of America estimates that there are 185,000 new lower extremity amputations each year just within the United States and an estimated population of 2 million American amputees [1]. Lower limb amputations have the greatest effect on the walking gait and balance. Common problems transfemoral amputees have are gait asymmetries, abnormal gait, increased energy expenditure [2] [3], and balance issues [4]. To attenuate these issues, many lower limb prostheses have been developed that can imitate the behavior of normal human walking and provide the possibility of recovering the damaged walking functions.

Even with the increasing number transfemoral and transtibial prostheses, passive prosthetic devices still dominate the prosthetic market. This is more than likely due to their ease of use and low cost of production. Currently, powered prosthetics are more expensive, heavier, and bigger than most passive prosthetics, due to actuators and gearboxes in the powered prosthetics. The added weights and bulky volumes increase the metabolic cost and may increase the risk of falling [3]. Therefore, to maximize the benefits (e.g., gait pattern generation, insertion of net power) of the powered prosthetics, it is important to design the powered prosthetics that can enhance biomechanical and metabolic outcomes compared to passive prosthetics. However, there have been few systematic studies that tried to enhance biomechanical and metabolic outcomes for the powered transfemoral prosthetics over a longer period with an approach of human-in-the-loop optimal design.

The purpose of this study is to propose the proof-of-a-concept study to design a powered transfemoral prosthesis that can enhance biomechanical and metabolic outcomes of the amputee gait. Specifically, we are interested in gait symmetry, and metabolic costs of the amputee gaits powered transfemoral prostheses. In this abstract, as a part of a long-term project, we present a preliminary data from one transfemoral amputee patient using a custom-built powered transfemoral prosthesis, called AMPRO I (A&M Prosthesis version I) (Figure 1).

Figure 1: Participant using AMPro I

METHODS

One healthy, 19 year old, male unilateral transfemoral amputee was recruited to participate in a case study to for initial analysis of AMPRO I. AMPRO I is the first generation of a powered transfemoral prosthesis developed at Texas A&M University. AMPRO I utilizes feedback from the human leg and force sensors to create the gait for the knee and ankle. The device has a height of 470mm and weight of 8kg. AMPRO I is a standalone powered prosthetic with the battery and control housed inside the device (Figure 1). Currently, AMPRO II, which has a smaller volume and a lighter weight, has been developed and being tested with various controllers.

To compare subject's own microprocessor-type (Genium, Ottobock, Germany) prosthesis and AMPRO I, subject's joint kinematics were collected and computed. When the subjects were wearing his own prosthesis, Vicon motion capture (Vicon, MX-T40S, Oxford, UK) was used to measure the joint kinematics of ankle, knee, and hip on both legs with the sampling frequency of 100 Hz. Note that the Genium kneek has capability of adaptive yielding control (via variable damping properties) for the knee joint. The ankle joint is completely passive. When the subject wore AMPRO I, the onboard encoder and inertial measurement unit (IMU) were used to compute joint angles for both legs.

Joint angle information was used to compute symmetry index between both limbs. The following symmetry index was used [5]:

$$SI = \frac{|x_r - x_l|}{\left(\frac{1}{2}\right)(x_r + x_l)}$$

where SI is the symmetry index, x_r is joint angle for the right leg and x_l is the joint angle for the left leg. Note that gait symmetry is quantified at discrete time points using the symmetry index (SI). The closer the value is to zero, the more symmetric it is. The closer the value is to 1, the more asymmetric the gait is.

RESULTS AND DISCUSSION

Bilateral joint angles for subject's own prosthetics and AMPRO I are given in Figures 2 and 3, respectively. When looking at the average SI over a gait cycle for the microprocessor knee and AMPRO I, AMPRO I had an approximately 5% lower symmetry index (lower is better) for the knee angle. However the ankle SI for AMPRO I was higher than the microprocessor knee (Table 1). This might be due to the fact that AMPRO I used a controller that assumes flat foot walking for practical reasons, meaning that the prosthetic did not experience heel-strike or push-off, but land flat on the ground. In order to alleviate this problem, multi-contact algorithm is currently being implemented (not presented in the abstract).

Although the improvements in knee symmetry are small, this shows promise for powered prosthetics. Even with flat foot walking, AMPRO I exhibits similar gait symmetry to the microprocessor-type prosthesis. Significantly improved gait symmetry is expected with multi-contact walking. It is also important to note that AMPRO I (8kg) significantly heavier than participant's microprocessor knee (about 3kg). A heavier prosthesis tends to increase energy expenditure and gait symmetry index. Therefore, a lighter powered prosthesis will likely yield more symmetric gaits.

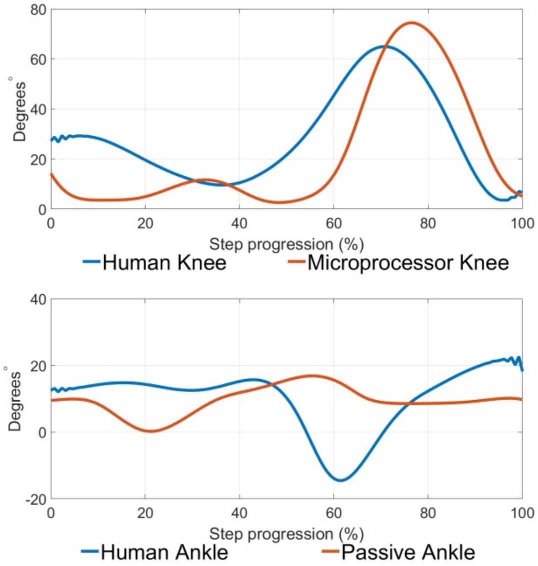

Figure 2: Knee and Ankle Angles with Participant using Microprocessor prosthetic

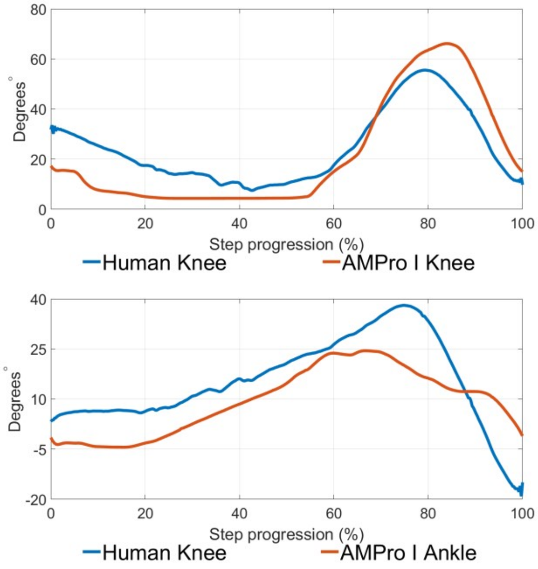

Figure 3 Knee and Ankle Angles with Participant using AMPro 1

Table 1: Knee and Ankle SI for Microprocessor Prosthetic and AMPRO 1

	Knee SI	Ankle SI
Microprocessor	.6588	.6406
AMPRO 1	.5920	.6693

FUTURE DIRECTIONS AND CONCLUSIONS

Even though this study presented only very rudimentary data, we are currently conducting many more biomechanical analyses including gait symmetry, net power, and energy expenditure (using VO2 Max). Furthermore, newly-developed AMPRO II has better features such as lighter weight (5kg), and smaller size (380mm). Along with these new features, a better control algorithm including splined-based optimization method [6] and multi-contact walking is currently being applied. A longitudinal study with 17 sessions are being conducted to follow up the biomechanical performances. This study will take these inputs from the users to improve the designs of the powered transfemoral prosthetics in the framework of human-in-the-loop design optimization. Our ultimate goal of this study is to enhance the performance of the powered transfemoral prosthesis so that gait symmetry and energy expenditure will enhance compared to passive prosthesis.

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